Satellite Technologies to Support the Sustainability of Agricultural Production

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Abstract Precision farming is a form of multidisciplinary and technologically advanced agriculture, which recourses to machines equipped with "intelligent systems," able to dose the productive factors (fertilizers, pesticides, etc.) according to the real needs of the homogeneous areas constituent to the plot (Verhagen and Bouma, Modeling soil variability. In: Pierce FJ, Sadler EJ (eds) The state of site specific management for agriculture. ASA Publications, 1997).

Experimental trials have been conducted in order to compare two satellite-guidance devices and two correction systems of the GPS signal: the EZ-Steer/RTK and Autopilot/EGNOS. The machines used in the tests were the tractor New Holland T7060, the rotary harrow Alpego DG-400, and the burier Forigo DG-45, to determine which of the two systems ensured the best quality of work. The results obtained showed that the EZ-Steer/RTK system guaranteed a lower stability of the theoretical trajectory than the Autopilot/EGNOS system, above 1.69 %. From the elaboration of data of the two guidance systems behavior to manage the only width of transposition, it is observed that the EZ-Steer/RTK system is able to guarantee a better hold of the line compared to the Autopilot/EGNOS system, which provides a mistake of 176 cm on the total width of transposition and 2 cm on the mean value. In the matter of the normalized transposition surfaces, the Autopilot/EGNOS system ensures a better work quality.

1 Introduction

Precision farming (PF) is a management philosophy or approach to the farm and is not a definable prescriptive system (Dawson 1997). It identifies the critical factors where yield is limited by controllable factors and determines intrinsic spatial variability. It is an essentially more precise farm management made possible by modern technology (Mandal and Ghosh 2000). The variations occurring in crop or soil properties within a field are noted and mapped and then management actions are taken as a consequence of continued assessment of the spatial variability within

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that field. The development of geomatics technology in the later part of the twentieth century has aided in the adoption of site-specific management systems using remote sensing (RS), GPS, and geographical information system (GIS).

This approach is called PF or site-specific management (Brisco et al. 1998; Carr et al. 1991; Palmer 1996).

The farming tends to manage every factor of production in varying measures, treating small areas inside the lot as separate surfaces. By doing so, the economic margin of crops can be increased, reducing the input the technical means. Furthermore, the environmental impact and the quantity of the production factors used, such as pesticides and fertilizers, are significantly reduced. Therefore, the precision farming aims to adapt the contributions in a point manner, taking into account the local variability of the physical, chemical, and biological characteristics of the field and the timing of implant (Pierce and Sadler 1997). At the same time, also the soil preparation work must be performed accurately, in order to avoid overlap, which would cause an increase of the costs. For this aim, a detailed mapping of the physical, chemical, and biological properties of the field has been used, so that they can be managed by the control computer of the cultivation operations, placed beside the machines. Therefore, the implementation of the actions demands an automatic positioning system (GPS, global positioning system), which allows the machine to recognize the exact location on the map, differentiating the agricultural operation to carry out. A group of 24 satellites in orbit around the Earth forms the GPS. With three satellites and a receiver and through the three-dimensional triangulation, the receiver will indicate its position on the Earth. That is done through the analysis of the high-frequency signals that the satellites send to the receiver, which calculates how long it takes to receive the signal and its position is displayed on a screen. In addition, it reduces the environmental damage and the risks in agriculture. During the crop production, the uncertainty of the yield may be reduced and the safety of the farmers' incomes can be increased if the technological elements are used and combined correctly (Auernhammer 2001; Gandonou et al. 2004; Chavas 2008).

Precision agriculture is a systems approach to farming. To be viable, both economic and environmental benefits must be considered, as well as the practical questions of field-level management and the needed alliances to provide the infrastructure for technologies.

That study was conducted to investigate the convenience in the use of two normally used system of guidance, examining their reliability and the opportunity of reducing production costs, and therefore also have a fuel saving, with clear environmental benefit.

2   Materials and Methods

The experimental trials were conducted on two satellite-guidance devices using two different correction systems of the GPS signal:

Fig. 1 Motorized roll

- The EZ-Steer, with RTK precision system
- The Autopilot, with EGNOS precision system

The EZ-Steer is an assisted guidance system, wherein the management of the tractor direction happens by a motorized roll, placed beside the steering, which is operated by the control unit positioned in the tractor cabin (Fig. 1).

This system doesn't overcome the value of 90 points (on a scale that ranges from 50 to 150), because of a non-instantaneous reaction of the starter to the course correction pulses issued by the control unit and because of the roll slipping light on the wheel; it was observed that, using a precision RTK and setting a value more than 90 points.

The Autopilot, instead, is an integrated system, which uses the hydrostatic guidance system for the management of the tractor through a hydraulic control unit (Fig. 2), which communicates with the control unit, placed in the control room.

In that case, the control unit communicates, both, with the GPS antenna and with the sensors proximal to the wheels, which indicate how the feed axis diverts respect to the orthogonal of the tractor. The Autopilot's hydraulic circuit, differently from the EZ-Steer, allows to work with a value up to 135 points before going in overcorrection, which means it has a remarkable ability to maintain the correct trajectory also on land which is full of holes and/or soft. The GPS with EGNOS error correction can obtain a positioning accuracy, which is a precision between consecutive passes, of 20 cm, and a repeatability year after year of 90 cm (it's a free service); the RTK, instead, is a high-precision technology, with an accuracy between consecutive passes of 2.5 cm and a repeatability year after year of 2.5 cm. The RTK is able to provide an elevation accuracy of 5 cm, with an improvement of almost two orders of height compared to the GPS standard (DGPS), since this system is able to extract the additional information, examining the carrier wave of the GPS signal (Tyler et al. 1997). The RTK system's disadvantages are a higher cost, the need to establish a local base station, and a significant decrease compared to the GPS standard methods. A light-bar provides information of the visual guide to the operator, who may make some corrections of manual steering.

Fig. 2 Hydraulic
control unit

During the trials in the field, the tractor New Holland T7060 was used, while as operating machines the following have been used:

- The rotary harrow, Alpego DG-400
- The burier, Forigo DG-45
- The rotary tiller, MASCHIO Pantera 420
- The plow scrambler, SILVER 66/15

It was decided to carry out investigations on flat surfaces and, in any event, not surrounded by mountains in the circumstances, so that the rover and the eventual RTK antenna could be served by the largest number of satellites; 8 plots away from trees, power lines, and farms were chosen as areas of experimental interest for the same reason, because these elements could create interferences between the receiver and the satellite.

To carry out the measurement, a tape measure to 20 m, a measuring tape from 3 m steel rods for reinforcement, and a line from carpentry, squaring surveyor have been used. The distance between each pair of pickets has been detected, obtaining the so-called length of transposition, except that, by connecting the two pegs with a fishing line, in order to detect the maximum distance, taken perpendicularly to the line, between the latter and the margin of transposition, identifying the width of transposition. The measurements were carried out over several days of the campaign and developed over a distance of 6,200 m for each of the systems examined. With regard to the eight plots, the measures that characterize them are summarized in Table 1 (Fig. 1).

The data collected for each of the two systems is not concordant; in fact, while for the EZ-Steer/RTK, 80 observations were carried out, for the Autopilot/EGNOS system, 75 observations were performed. But it is an obvious consequence, since the two systems are independent, while what makes them comparable is the fact that they have been tested on a common route of 6,200 m. So for the analysis of variance (ANOVA), it is necessary to standardize the number of measured data.

Table 1 Size of 8 plots

	EZ-Steer/RTK				Autopilot/EGNOS			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
Greater side (m)	120	125	110	115	120	140	130	125
Smaller side (m)	90	80	95	90	85	75	80	85
Surface (ha)	1.08	1.00	1.06	1.04	1.02	1.05	1.04	1.06

3 Results

The experiments were performed over several days in the countryside on a route of 13,000 m and 80 observations for each plot. The basic parameters that have characterized the two trials are summarized in Table 2 and in Table 3 are the machine operating data.

The surveys have been performed on pairs of contiguous swaths, to identify areas where an overlap or some variations happen, so that even the measure results reasonable.

For each transposition, then, the apparent area has been calculated, multiplying the transposition length for its width. Obviously, since in the analysis of variance for one factor (ANOVA) it is necessary to standardize the number of the detected data, to the nonexistent data, a value of 0 has been assigned and the average was calculated considering these terms.

Thanks to the elaboration of data in relation to the behavior of the two satellite-guidance systems that manage the only direction of tractor advancement, we have obtained the following results in Table 4.

On the basis of these results, you gather that the EZ-Steer/RTK system ensures a lower capacity of the theoretical path; in fact, the total of the traveled route shows an error of 229.42 m and with respect to the Autopilot/EGNOS system above 3.806 %. From the elaboration of data relating to the behavior of the two guidance systems in managing only the transposition width, we have obtained the following results in Table 5.

Regarding to longitudinal measures, the quality of work is given by the optimal length of transposition anything, from a comparison of the data shows how complex the EZ-Steer/RTK, despite surgical correction of the accuracy of the satellite signal ensured by RTK, ensures a lower seal of the theoretical trajectory, in fact, the total of the journey performed, shows a longitudinal transposition of 229.42 m more than the Autopilot/EGNOS system, equal to 3.806 % of 6,200 m paths. It follows that, between the two systems, the Autopilot/EGNOS is able to correct before and better the deviation from the theoretical trajectory.

Each system consists of two devices, each of which has a different ability to correct the accuracy, the RTK and the EGNOS, and to manage the accuracy, EZ-Steer and Autopilot. EZ-Steer is a guidance system of the type witnessed soothe control of direction of the tractor is the case for action on the steering board of a roll

Table 2 Basic nominal geometric parameters

	EZ-Steer/RTK	Autopilot/EGNOS
A swath average length(m)	118	130
Total number of passes made	52	48
Meters traveled (m)	6,136	6,240
Contiguous passes' number	26	24
Single pass width (m)	4.07	4.07
Two contiguous passes' width (m)	8.15	8.15
Swath total width (m)	211.5	194.65
Two contiguous passes' surface (m^2)	961.7	1,059.5
Σ of work surface (m^2)	24,957	25,304.5

Table 3 Operative data of the machines

	Forigo DG-45 New H. T7060	Alpego DG-400 New H. T7060	Zappatrice MASCHIO Pantera 420 New H. T7061	Aratro rimescolatore SILVER 66/15 New H. T7062
Average speed (km/h) (m/min)	3.6; 60	4.0; 66.7	3.8; 60	6.0; 69.7
Work front width (m)	3.8	4.00	4.20	4.30
Processing depth (m)	0.2	0.1	0.29	0.25
Fuel consumption (l/h)	15.4	15.8	16.10	15.80

Table 4 Transposition length results

	EZ-Steer/ RTK	Autopilot/ EGNOS	Variation
Average length of a swath (m)	118	130	−2
Total route traveled (m)	6,136	6,240	−104
Total transposition length (m)	998.64	769.22	229.42
Transposition average length (m)	12.493	9.6153	2.877
Transposition length of total traveled route (%)	16.275	12.469	3.806
Minimum transposition length (m)	1.3	2.45	−1.15
Maximum transposition length (m)	28.7	17.1	11.6

motor, the management of which, in turn, is assigned to the control unit accommodated in the tractor cabin; it is such an architecture that focuses on the limit of the EZ-Steer system to allow the tractor to emphasize the theoretical path, and because the motor cannot handle the multiple pulse course correction issued by the control unit, it shows a very ready reaction to them, except that, roll films are observed with

Table 5 Transposition width results

	EZ-Steer/RTK	Autopilot/EGNOS	Variation
Width of the work front (m)	4.075	4.075	0
Width of two contiguous wipes (m)	8.15	8.15	0
Swaths' total width (m)	**52.875**	**48.6625**	**4.2125**
Total transposition width (m)	**11.6**	**13.237**	**1.64**
Average transposition width (m)	**0.145**	**0.165**	**0.02**
Minimum transposition width (m)	0.05	0.08	0.03
Maximum transposition width (m)	0.355	0.375	0.02

slight shifts on the steering wheel, which reduce the sensitivity of the system. All these elements are summarized by the aggressiveness parameter, which explains the ability of the system to follow a rectilinear profile and faithful to the trajectory theoretical.

There is, however, a limit, called overcorrection and is proportional to the architecture of the system. The EZ-Steer system, however, is implemented by an RTK correction, with an experimental aim to compensate greatly reduced aggression and, therefore, to significantly reduce the length of implementation, even bringing it below what would have been possible with an Autopilot/EGNOS system. In the EZ-Steer/RTK, the transposition length equals to 998.64 m, while for the Autopilot/EGNOS system, transposition length equals to 769.22 m. Apparently, the ability to control the actual trajectory on the racing line and therefore the aggressiveness of the two drive systems, the EZ-Steer and Autopilot, are likely to prevail on the correction accuracy of the satellite signal carried by the devices and RTK EGNOS.

The results on the widths of transposition, instead, in a sense, stressing the different correction capabilities of precision, were made by the RTK mode and the EGNOS mode, in fact, whereas with the Autopilot/EGNOS system, it has an average width of transposition equal to 16.5 cm, with the EZ-Steer/RTK an average width of transposition of 14.5 cm. For all EZ-Steer/RTK, 14.5 cm is, however, a result that does not respect the potential of 2.5 cm RTK correction, while the complex Autopilot/EGNOS is fully integrated in the range of 20 cm guaranteed by the EGNOS correction. The reason, also in this case, is attributable to the aggressiveness of the two different driving systems, satellite; this is because the aggressiveness of 90 points induces the tractor to be moved further from the ideal trajectory, unlike what happens with the high aggressiveness of 135 points obtained on the Autopilot.

With regard to operating machines, the Autopilot/EGNOS and the EZ-Steer/ RTK showed a homogeneous regularity of work due to the ability of stabilizing active suspension of the tractor New Holland T7060, except that the regularity of the surfaces were the backdrop to the trials and machinery.

An analysis of variance (ANOVA) on the lengths of transposition is that the calculated F (F) is greater than the critical value of F (Fcrit), except that as the value of significance (p value) is less than the value of reliability ($\alpha = 0.05$), we reject the

null hypothesis (H0), which suggests that there is no significant difference between the means, and accept the alternative hypothesis (H1), which emphasizes, however, that there is a significant difference between the means; therefore, this means that the values of length of transposition collected in the field for the EZ-Steer system/ RTK and Autopilot/EGNOS deviate significantly from the average. With regard to the widths of transposition and similarly the length of implementation, the analysis of variance showed that the calculated F (F) is greater than the critical value of F (Fcrit); we reject the null hypothesis (H0), which suggests that there is no significant difference between the means, and accept the alternative hypothesis (H1), which tells us that the means are significantly different from each other. Therefore, from what the analysis of variance shows, the values of transposition length collected in the field for the two systems differ significantly from the average.

In the analysis of variance on the standard surfaces, differently from what happens with the length and width of a transposition, it appears that the calculated F (F) is less critical than the F (Fcrit) and the significance value (p value) is greater than the value of reliability ($\alpha = 0.05$); we accept the null hypothesis (H0), which suggests that there are significant differences between the means, and reject the alternative hypothesis (H1), which tells us that the means are significantly different from each other. The analysis of variance on standard surfaces, so that the values obtained for the EZ-Steer/RTK and the Autopilot/EGNOS do not differ significantly from the average.

Relating to the data collected about the transposition width and the total width of the work front, the results are summarized in Table 6.

The collected data showed that the Autopilot/EGNOS system is useful ensuring a better quality of work than the EZ-Steer/RTK system; in fact, it provides a precision on the transposition total area, approximately 6,200 m^2. The area of transposition, therefore, is the parameter that most of all allows to compare the two combinations of guidance systems, as it is a datum that merges the longitudinal behavior of transposition with the latitudinal one. As for the transposition width also for the surface of transposition, the proportion (%) of the transposed area is not considered with respect to the total worked area, in that with increasing the work front and, therefore, the surface unitarily worked and the surface transposed being equal, it follows its reduction if we consider it in percentage terms.

The average depth of work respects the operating nominal depth when the tractor is supported either by the EZ-Steer/RTK system or by the Autopilot/EGNOS system. The analysis of variance (ANOVA) affected parameters such as transposition length, transposition width, and normalized areas. For the calculation of the variance of the transposition length, we have analyzed the data obtained, which have reported in the graph relative to the transposition lengths provided by the two guidance systems (Graph 1).

The results obtained showed that the values of transposition length surveyed in the field for the EZ-Steer/RTK and the Autopilot/EGNOS systems one deviate significantly from the average. Like to the calculation of the variance of the transposition width, the data collected have been analyzed which have shown in

Table 6 Results on the surface of transposition

	EZ-Steer/RTK	Autopilot/EGNOS	Variation
Area of two contiguous wipes (m^2)	3,847	4,238	−391
Total worked area (m^2)	24,957	25,305	−348
Total transposition area (m^2)	**11,484.36**	**10,182.17**	**1,302.19**
Transposition average area (m^2)	**1.81**	**1.59**	**0.22**
Minimum transposition area (m^2)	**0.065**	**0.196**	**−0.131**
Maximum transposition area (m^2)	10.19	6.5	3.69
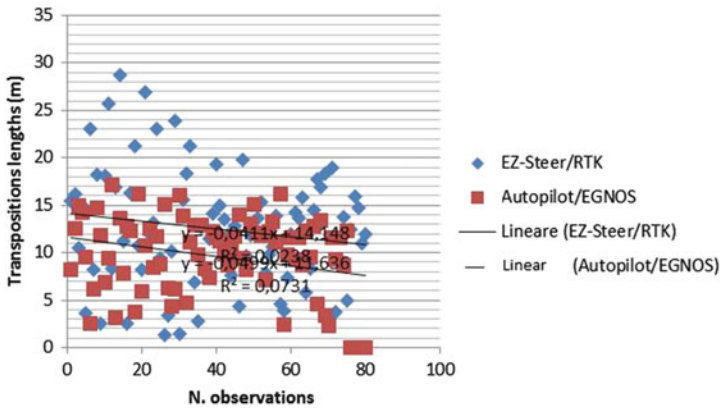
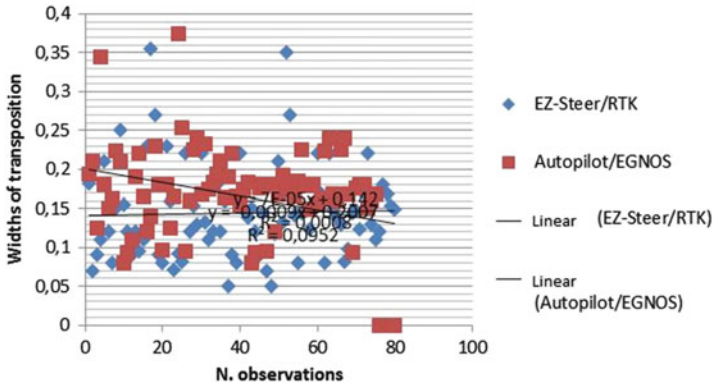**Graph 1** Transposition lengths provided by the two guidance systems

the graph of the transposition widths provided by the two guidance systems (Graph 2).

For the calculation of the variance of the transposition normalized areas, obtained by multiplying for each survey the transposition length for its width, we have analyzed the collected data which have shown in Graph 3.

The analysis of variance on the normalized areas shows that the values obtained from the systems EZ-Steer/RTK and Autopilot/EGNOS do not deviate significantly from the average.

The survey results are summarized in Table 7 to deduce the behavior of the two systems and draw conclusions.

In longitudinal terms, a good work quality is given by the null transposition length. It's clear from the comparison with the data that the EZ-Steer/RTK system provides a lower capacity of the theoretical trajectory. In fact, the total of the route that has been carried out shows a longitudinal transposition of 229.42 m more than the Autopilot/EGNOS system, equal to 3.806 % of 13,000 m routes. It follows that, between the two systems, the Autopilot/EGNOS is able to correct before and better the deviation from the theoretical route.

Graph 2 Comparison between the transposition widths provided by the two guidance systems
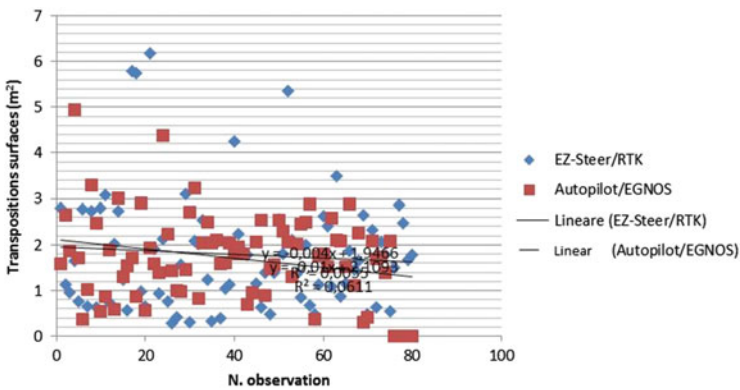
Graph 3 Comparison between the transposition normalized surfaces provided by two guidance systems

Table 7 Results about the two guidance systems

	EZ-Steer/ RTK	Autopilot/ EGNOS	Variation
Total transposition length (m)	**998.64**	769.22	229.42
Average transposition length (m)	**12.483**	9.6153	2.87
Variance – average transposition length	**38.3352**	18.3766	19.96
Percentage of the transposition length on the total of traveled route (%)	**16.275**	12.469	3.806
Total transposition width (m)	11.6	**13.237**	−1.64
Average transposition width (m)	0.145	**0.165**	−0.02
Variance – transposition average width	0.0037	**0.0043**	0.00
Total transposition area (m^2)	**11,484.36**	10,182.17	1,302.19
Average transposition area (m^2)	**1.81**	1.59	0.22
Variance – average transposition area	**1.5861**	0.888	0.70

4   Conclusions

Experimentation has shown that the two satellite-guidance systems examined had no significant differences in the quality of work, although the complex autopilot/EGNOS has a higher reliability on the length of transposition. It follows that the two combinations of satellite guidance, in view of the similar amount of latitudinal transposition, make it suitable for all those jobs which tolerate such an error, such as plant protection treatments, fertilizing, harrowing, mowing, harvesting, etc., while for jobs requiring great precision, e.g., sowing, weeding, planting, and processing of files, there is the need to use a combination that guarantees maximum precision and, therefore, to optimize the system supporting it with the Autopilot RTK correction. The maximum precision that results, however, also involves the greatest savings on the factors of production; therefore, this solution would be desirable to also increase their procurement costs and increase with firm size.

Otherwise, that study wanted to check the accuracy of only the devices RTK and EGNOS, and this would have raised the need to follow a different approach to the findings; in fact, it would be necessary to use a single device driving, such as Autopilot, except that it would be necessary detecting the precision of the real trajectory in relation to time.

The precision between consecutive passes measures the relative accuracy of 15 min intervals, e.g., a receiver with precision between consecutive passes of 2.5 cm allows to work for 95 % of the time with an offset or overlap less than 2.5 cm. Also, the precision year after year is a measure of repeatability over the time of the accuracy or the ability of the same rows after 1 day, 1 week, 1 month, or 1 year.

At the actual level of technology there are many perspectives of full automation in agriculture, thanks to the use of robots and of internet, which would improve the transfer of data even thousands of miles away. This change, although it has its economic value, may also represent the input to give importance to agricultural systems, to date, the common feeling, less attention apparently more powerful than loans qualifying, and also seeking new employment prospects, requiring more and more people able to open your mind multidisciplinary interaction. In conclusion, a snapshot of the distribution of the solutions of precision agriculture in Italy, if taken today, allows to highlight how in recent years the development of this sector has been slow due to the reorganization of the company structure, reducing the number of operators and increasing the size and strength of the business of some figures between farms and agromechanical.

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